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Session TP1
Room 1
2:30 - 5:30 p.m.

**Mechanisms of Cardiopulmonary
Adaptation to Microgravity - 2**

AUTONOMIC REGULATION OF CIRCULATION AND MECHANICAL FUNCTION OF HEART AT DIFFERENT STAGES OF 14-th MONTH SPACE FLIGHT

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INTRODUCTION

The flight of doctor-cosmonaut V.V. Polyakov is the most prolonged in history of manned space flights. In this flight the autonomic regulation of circulation and mechanical function of heart were studied.

METHODS

Heart rate variability analysis, ballistocardiography (BCG), seismocardiography (SCG) and 24-hour registration of ECG (Holter monitoring).

RESULTS

As have shown the results of researches, during the first half-year the changes of main cardiological parameters did not differ practically from the similar changes, observed at other cosmonauts. However, from the second half-year of stay under weightlessness conditions the following changes were detected for V.V. Polyakov: a) There is a tendency of heart rate decreasing during flight in comparison with the beginning of flight, especially it is expressed in a night period of day. b) For 7-8 months of flight the growth of low frequency (LF) spectral power of heart rate variability in a range 0.05-0.015 Hz and reduction of high frequency (HF) spectral power in a range 0.5-0.15 2Hz, which characterize the growth of sympathetic activity, are observed. c) At 8-10-th months of flight the relative spectral power in minute band to hour band for fluctuations of heart rate and other physiological parameters increases. The period of these fluctuations has been also increased. d) The amplitudes of BCG and especially of SCG tend to essential growth in the second half of flight. The SCG/BCG relation at the end of flight is increased. e) The growth of day-averaged values of middle frequency (MF) spectral power of heart rate variability (0.15 - 0.05 Hz), which reflects the activity of vasomotor center, is observed.

CONCLUSION

From the second half-year of stay under weightlessness conditions the decreasing of heart rate, the growth of vasomotoric center activity and the changes of periodicity and power of superlow fluctuations of physiological parameters, which reflect the activity of subcortical cardiovascular center and of higher levels of vegetative regulation, are observed. The growth of total (SCG) and external (BCG) work of heart in the last months of flight has been also marked. All this gives us the basis to consider the observed changes as the result of developing of additional compensative mechanisms, directed on maintenance of blood pressure and of adequate circulation under new conditions.

Cardiovascular oxygen transport in exercising humans in microgravity

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Oxygen consumption ($\dot{V}O_2$), by a closed circuit method, heart rate, by electrocardiography, cardiac output (\dot{Q}), by the one-step CO_2 rebreathing method, blood hemoglobin concentration (Hb), by a photometric technique, and arterial oxygen saturation (Sa,O_2), by infrared oxymetry, were measured at rest and at the steady-state of three submaximal cycloergometric work loads (50, 75 and 100 W respectively) on two Cosmonauts before (1 g) and during (0 g) a 6-month-duration spaceflight on board the Russian Space Station MIR. Oxygen delivery was calculated as the product of \dot{Q} times Sa,O_2 times Hb times the physiological oxygen binding coefficient (1.34 ml l^{-1}). $\dot{V}O_2$ was linearly related to power both pre- and in-flight. At 0 g, $\dot{V}O_2$ did not change as a function of flight time. At any work load, $\dot{V}O_2$ was significantly lower at 0 g than at 1 g (-18.5 % and -13.8 % for subject 1 and 2, respectively). Similarly, lower \dot{Q} values at exercise, independent of flight time, were found at 0 g than at 1 g (-8.1 % and -15.4 %, respectively). The \dot{Q} vs $\dot{V}O_2$ relationship at exercise was the same in the two conditions. Resting \dot{Q} was higher at in-flight than pre-flight, because a significant increase in stroke volume was only partially compensated for by a decrease in heart rate. The heart rate vs power relationships during exercise were slightly displaced upward at 0 g. No changes in stroke volume during exercise at 0 g were found. The concomitantly decreased (subject 1) or unchanged (subject 2) Hb at 0 g contributed to a significant decrease in oxygen delivery (-17.6 % and -11.2 %). The relationships between oxygen delivery and oxygen consumption were the same at 0 g as at 1 g in both subjects. This data reveal a tight coupling of cardiovascular response to exercise and peripheral metabolic demand. They suggest that the regulation of cardiovascular oxygen transport during exercise may predominate over fluid balance and blood pressure regulation.

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VENOUS HEMODYNAMIC CHANGES ASSESSED BY AIR PLETHYSMOGRAPHY DURING A 16- DAY SPACEFLIGHT.

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INTRODUCTION.

The aim of the present study was 1/ to assess the feasibility of using Air Plethysmography as a valuable tool for studying venous hemodynamic changes during spaceflights and 2/ to have a more complete understanding of venous changes occurring in the legs during exposure to real microgravity. Air plethysmography was implemented during the past French - Russian mission CASSIOPEE on board the MIR station, within the framework of the PHYSIOLAB project.

METHODS.

Measurements were done on the French spationaut and on one Russian cosmonaut.

The Air plethysmograph consists of an instrument derived from the Air Plethysmograph APG 1000 (ACI corporation, Sun Valley, California), adapted for Space utilization. It consists of a long air cuff (suitable for legs and forearms) which measures limb volume changes. The cuff is connected to an air pump which assures its inflation. The plethysmograph is connected to a central processing unit whose aim is to manage the measurement session, to process and register data and to transfer experimental data to earth by telemetry. Different parameters were measured by venous occlusion plethysmography : leg compliance (pressure - volume curve of the leg) and venous capacity at different counterpressures, arterial flow index, venous filling index, venous filling time, ejection fraction, residual volume fraction and half-emptying time. Measurements were done before flight (twice), 3 times during flight and 3 times during post-flight recovery.

RESULTS.

Results obtained on the French and Russian cosmonauts showed : 1/ during flight, a tendency towards greater venous capacities at low counterpressures (10, 20 mmHg) without changes in venous compliance (compatible with a decrease in venous pressures), increases in venous filling time, capillary filtration rate and half-emptying time and decreases in arterial flow index, venous filling index and ejection fraction; 2/ after flight, the period just following return to earth (R₊) was characterized, for the French cosmonaut, by a considerable increase in half-emptying time and decrease in ejection fraction. All parameters progressively returned to their control value at the end of the first week of recovery.

CONCLUSION.

These results show that during exposure to real microgravity, the pattern of venous hemodynamic changes is complex, and characterized by alterations of venous distensibility as well as by alterations of venous filling and emptying, leg muscle pump and capillary filtration rate. These alterations are compatible with the involving of venous network in the orthostatic intolerance syndrome occurring in astronauts during and after re-entry.

RESPIRATORY MECHANICS AFTER 180 DAYS SPACE MISSION (EUROMIR'95)

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INTRODUCTION

Several aspects of respiratory physiology, as lung and chest wall mechanics, regional blood perfusion and ventilation and consequently gas exchanges are greatly affected by gravity. Therefore, major changes ought to be expected when the respiratory system is exposed to microgravity. The present study reports data on static lung volumes and pressure-volume relationship of lung and chest wall following the 180 days long European - Russian EuroMir '95 space mission.

METHODS

The experiments were performed on 2 crew subjects. Lung volumes were calculated through integration of the respiratory flow signals obtained from a flowmeter (Isler-CIR-Innovision, Switzerland, Denmark). Esophageal pressures were measured via an esophageal balloon placed in the second third of the esophagus and connected to a pressure transducer (Innovision, Denmark). Pressure and volume data were simultaneously recorded during: quiet breathing, slow vital capacity (VC), inspiratory (IR) and expiratory (ER) relaxation performed against a resistance of 2.44×10^{-3} (cmH₂O·min)/liters starting from 0 and 100 % VC, respectively. The maneuvers were performed in the sitting and the supine posture. Esophageal pressure during slow VC reflected the pleural pressure exerted by the lung elastic recoil, whereas esophageal pressure obtained during the relaxation maneuvers reflected the chest wall recoil pressure.

RESULTS

Data presented refer to pre-flight (5 sessions of Baseline Data Collection, BDC) and post-flight (on Return + 1, 10, 12, 27 and 120 days) experiments. On day R+1, VC decreased by 21 and 30 % in sitting and supine posture, respectively, relative to the pre-flight BDCs. This decrease progressively waned and disappeared on day R+ 27. The decrease in VC occurred because of a reduction of the inspiratory and expiratory reserve volume. Lung compliance, estimated at a lung volume closed to functional residual capacity, was not significantly different after flight compared to pre-flight BDCs, averaging 0.28 liters/cmH₂O. Pre-flight chest wall compliance was 1.1 and 0.6 liters/cmH₂O in supine and sitting posture, respectively. After return chest wall compliance decreased to 0.3 liters/cmH₂O in both positions and remained unaltered up to 120 days.

CONCLUSION

The data shows that a space mission as long as 180 days primarily alters chest wall mechanics and weakens the action of respiratory muscles.

ASSESSMENT OF THE SYMPATHETIC AND THE PARASYMPATHETIC NERVOUS ACTIVITY DURING PARABOLIC FLIGHT BY PUPILLARY LIGHT REFLEX

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INTRODUCTION

The pupil of the eye can be a non-invasive monitor of the autonomic nervous activity. Because it is controlled by iris : sphincter and dilator which are innervated by the parasympathetic and sympathetic nerve, respectively. Previously, we proposed a method for assessing the autonomic nervous activity from pupillary behavior^[1,2]. In this study, we improved the method and attempted to evaluate the sympathetic and parasympathetic nervous activities under hyper- and hypo-gravity during a parabolic flight.

AUTONOMIC NERVOUS ACTIVITY ASSESSMENT METHOD

The method proposed previously, based on the analysis of internal property of human pupillary muscle system model^[3], enables a separate assessment of sympathetic and parasympathetic nervous activity from the changes in pupillary single flash response. However, relatively low gain of the dilator system compared with the sphincter makes it difficult to estimate the sympathetic nervous activity. The improved method utilizes comb-like flash stimulus which activates dilator system more efficiently than a single flash stimulus. The other part of the method is the same as in the previous method^[1,2]. The validity was proved by a study using autonomic nervous drugs.

PARABOLIC FLIGHT EXPERIMENT

Parabolic flight experiment was conducted by DAS MU300, a rear engine jet. Subject was a male university student. Stable pupillary responses to comb stimuli(Fig.1) could be measured by a face-attached TV pupillometer^[4].

RESULT

In hyper-gravity, significant change in activities both of sympathetic and parasympathetic nervous system was not seen comparing to ground 1G condition. On the other hand, in hypo-gravity, the sympathetic nervous activity was slightly activated, whereas the parasympathetic nervous activity was inhibited.

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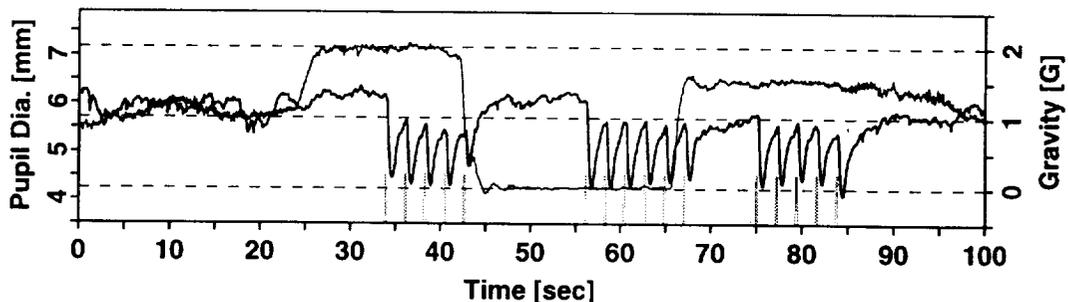


Fig.1 : Pupillary responses to comb stimuli during parabolic flight
Thick black : pupillary responses, thin black : gravitational changes, gray : comb-like flash stimuli

VASCULAR RESPONSE TO DIFFERENT GRAVITY

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Cardiovascular response to og exposure during 14 day space flight

- > Cardiovascular investigations were performed according to two programs ;
 1. At rest ; to study the cardiovascular adaptation to og at the level of - the heart
 - the deep vessels
 - the superficial vessels.
 2. During Low Body Negative Pressure (LBNP) ; to evaluate the orthostatic tolerance of the astronaut.
- > The results don't showed hypovolemia of the astronaut, but
 - a very stable cardiac volume
 - a very stable cardiac output = which is in agreement with the stability of volemia regulatin hormones.This is probably due : (1) to the inflatable cuffs "bracelet" that the astronaut maintained on the upper part of the thigh during the first inflight days
 - (2) and to the exercise
 - (3) and LBNP sessions performed inflight.This situation may explain the absence of significant renal flow resistance changes.
- > In the lower limits, the femoral flow was reduced although the vascular resistances were decreased and restable. This pattern is in favor of a vascular disadaptation which was confirmed by the LBNP test.
- > Finally the cardiovascular system adapts more progressively to the og exposure when using the thigh cuffs. But ; the vascular deconditioning still develops probably in relation with the deterioration of the peripheral venous/muscle system and the loss of sensitivity of the baro-reflex.

Artificial gravity as a tool to prevent cardiovascular deconditioning in space.

Cardiocirculatory responses to short radius rotation and exercise in human centrifuge.

- Cardiac Output (CO)
- Functional Residual Capacity (FRC)
- Arterial Blood Pressure (ABP)
- Heart Rahe (HR)

Were measured non invasively on six healthy males during submaximal cycloergometric exercise (50 W-150 W) under standard (1 g) or hypergravity conditions (1,41 g) obtained on a human centrifuge. The latter were chosen to simulate the "Twin Bikes System" (TBS). In conclusion the data show that the TBS can be appropriately utilized to maintain the cardiovascular conditions of the astronauts and that the pulse contour method can be appropriately utilized under hypergravity conditions.

- > During prolonged Space Flight, exposure to microgravity (μg) has profound effects on the human body, particularly so on ;
 - the musculo-skeletal system
 - the cardio-circulatory system (μg deconditioning).
- > Indeed the cardiovascular system is challenged by two major interacting conditions :
 - (1) The loss of the hydrostatic gradients that normally prevail in the upright position at 1g.
 - (2) And, a reduction of the functional demands due to μg .
- > The effects of the adaptation to μg become evident upon the return of the astronauts on Earth, and consist mainly of ;
 - muscular hypotrophy and weakness
 - bone demineralization
 - arterial hypotension
 - orthostatic intolerance
- > To avoid μg -deconditioning, two major classes of countermeasures have been developed in the past. They consist in maintaining the physical fitness by muscular exercise, or in mimicking the gravitational effects on the musculo-skeletal and circulatory system.
- > We assist today to a renewal of interest in the possibility to simulate gravity in Space (artificial gravity) by means of centrifugal forces obtained by the rotation of the Space module on its axis.
- > We have suggested to combine the benefits of exercise with those of artificial gravity by the use of two mechanically coupled bicycles counter rotating at the very same speed along the inner wall of a Cylindrical Space Module.
The characteristics of this proposal, the TBS, have been described.

- > In conclusion, these observations suggest that the TBS can be appropriately utilized to maintain the physical fitness of the astronauts, and that the cardiovascular load it includes is sufficient to prevent the microgravity deconditioning.

References

Fifth European Symposium on Life Sciences Research in Space
Arcachon, France, 26 september - 1 october 1993
ESA SP-366, august 1994